Proceedings of the 17th International Symposium on the
Packaging and Transportation of Radioactive Materials
PATRAM 2013
August 18-23, 2013, San Francisco, CA, USA

Probabilistic risk assessment on maritime transportation and port cargo handling of spent nuclear fuel

Yoshihiro HIRAO, Mitsufumi Asami, Hiromitsu Mochizuki
National Maritime Research Institute, Tokyo, Japan

Tsuneyasu Yamanaka
Japan Nuclear Energy Safety Organization, Tokyo, Japan

ABSTRACT

Spent nuclear fuels (SNF) of Japan have been transported by sea under an exclusive vessel with high seaworthiness. A high level of safety has been ensured by domestic regulatory actions according to the IAEA regulations. That is proved by a long history of safe transportation achieved to date. Meanwhile, by the start of operation of nuclear fuel cycle facilities including an interim storage, safety concerns are raised regarding near-future increase of the traffic of radioactive materials. For that reason, the relevant data has recently been prepared to assess the transport risk quantitatively, aiming at the proactive safety planning based on the perception of potentially hazardous situation and the risk information.

Principal feature of Japan's SNF transportation is both a coastal shipping operation and a port cargo handling by crane. We have developed the risk evaluation process and method suitable for the domestic environment. This study provides a few of the methods for identifying potentially significant accident using the accident-scenario management system, and evaluating an occurrence frequency of the accident for vessel and crane. Note however that it is conservatively estimated on the basis of general accident statistics due to lack of actual data.

Then a case study of shipping SNF along the Pacific coast of Japan was carried out to demonstrate the applicability of estimated data. It was found that most part of the accident risk could be contributed from a vessel foundering, then followed by package drop from crane. The general survey also revealed that quite a few cases of foundering are caused by severe weather conditions, without any collision or fire. A radiological impact by foundering depends heavily on two factors, water depth distribution along the route and ingestion population of contaminated marine-products. The latter is one of the major sources of uncertainty. Even under conservative assumptions, the future-planned

health risk will stay very low at a comparative level with the train-accidental risk of the Yucca Mountain EIS.

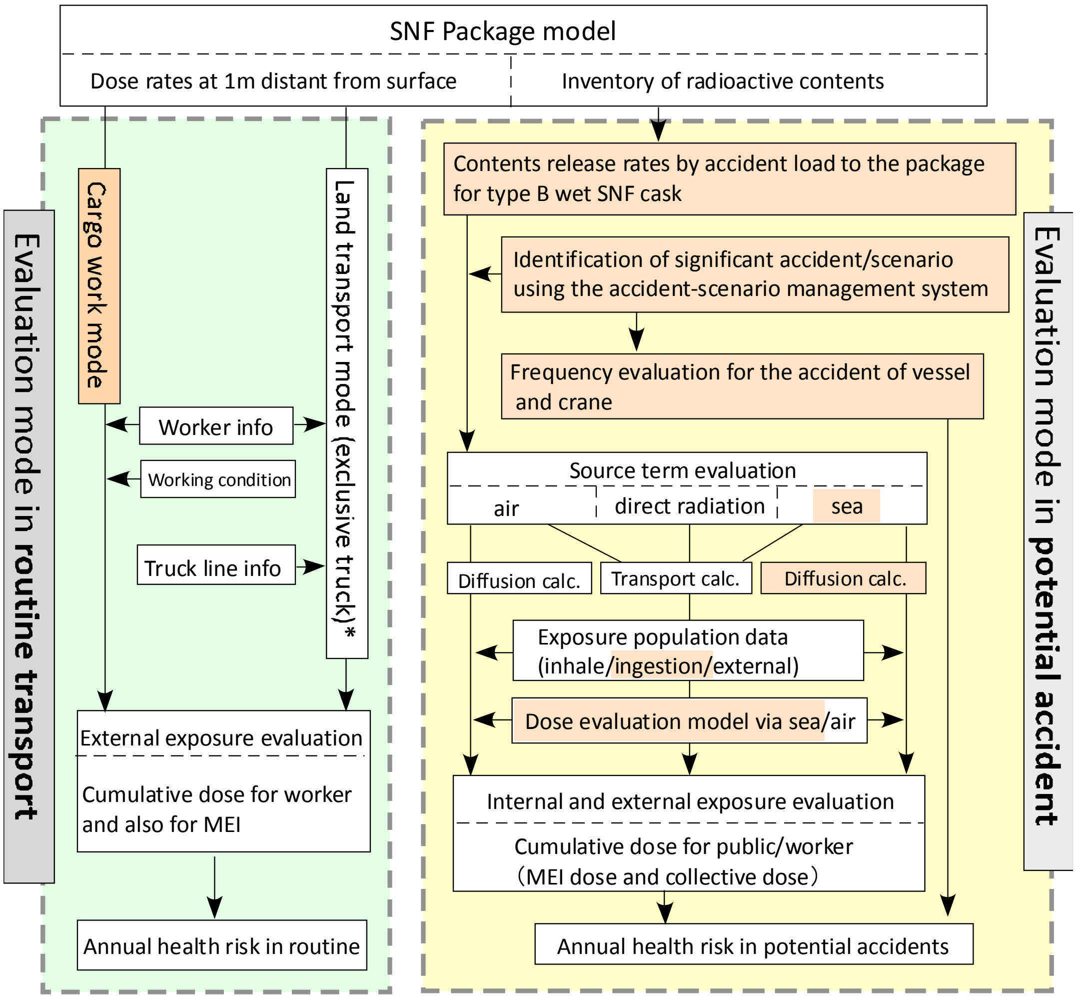
1 Introduction

Spent nuclear fuels (SNF) of Japan have been safely transported by sea using an exclusive vessel. Meanwhile, by the start of operation of nuclear fuel cycle facilities including an interim storage, safety concerns are raised regarding near-future increase of the traffic of radioactive materials. For that reason, the relevant data has currently been prepared to assess the transport risk quantitatively, aiming at the proactive safety planning based on the perception of potentially hazardous situation and the risk information. Principal features of Japan's SNF transportation are a coastal shipping operation and a port cargo handling by crane. We have developed the risk evaluation process and method suitable for the domestic environment. This study provides a few of the methods for identifying potentially significant accidents using the accident-scenario management system, and evaluating an occurrence frequency of those accidents for vessel and crane. Finally, a case study of shipping SNF along the Pacific coast of Japan was tentatively carried out to demonstrate the applicability of our estimated data. The transport risk is basically calculated according to methodology of the RADTRAN5[1]. The risk profile of potentially significant accidents and features of the health risk will be shown.

2 Development of risk evaluation process and methods suitable for domestic SNF transport environment

Figure 1 shows the risk evaluation process suitable for domestic transport environment. Principal feature of Japan's SNF transportation is both a coastal shipping by vessel and a port cargo handling by crane, whereas most countries including US have chosen land transport by truck or train. The process is developed on the basis of that of the RADTRAN5, however newly developed methods and data indispensable to our environment have been added. The process has two evaluation modes of routine transport and potential accident. In routine transport, it has such a merit that public exposure does not occur since there is no public around the marine route and a port in operation. Instead it is necessary for cargo workers to evaluate cumulative dose since they sometimes work in the immediate area of package without any substantial shielding[2]. For crews of an exclusive vessel, there is almost no radiological risk due to shielding by vessel itself and a dedicated wall. The same thing can be said for short-distance land transport between port and facility.

For evaluation process in potential accidents, accident scenario potentially significant for the accident risk must be identified first. The accident-scenario management system has been developed to support the task[3]. For the accidents of vessel and crane, an occurrence frequency data has been estimated in an accurate manner[4]. The radioactivity release rates of our wet cask have been prepared by type and degree of accident load, on the basis of methodology of NUREG/CR-6672 and IAEA TECDOC-1231[4]. Concerning the radiological impact from vessel accidents such as foundering, in particular the exposure pathway through the seawater must be considered. We have also developed methods and data for predicting radioactivity diffusion in the sea and evaluating both internal dose from ingestion of contaminated marine-products and external dose from seawater[5]. Two of these methods will be described in the following chapter.



* Land transport mode is provided for comparison use only. Exposure for public/worker is practically negligible.

Figure 1. Risk evaluation process suitable for domestic transport environment

3 Development of evaluation method and data for domestic transport

3.1 Identification of potentially significant accidents using the accident scenario management system

The accident scenario management system has been developed to collect potential accident scenarios from local experts and then identify major ones significant for the transport risk[3]. Figure 2 shows the page structure of the system which is designed as web application of groupware via Internet. Experts can access and edit the SWIFT (Structured What-IF Technique) sheet to add the information of potential accident such as general description, scenario and risk indices. Two types of risk indices are used to roughly evaluate occurrence frequency and severity of influence for each scenario. After all, we have picked up ones with relatively high indices among all the collected to identify the significant accidents. Table 3 shows an identification example of six potential scenarios for domestic transport case. This system is useful for enhancing the transparency of screening process and the comprehensiveness in risk findings.

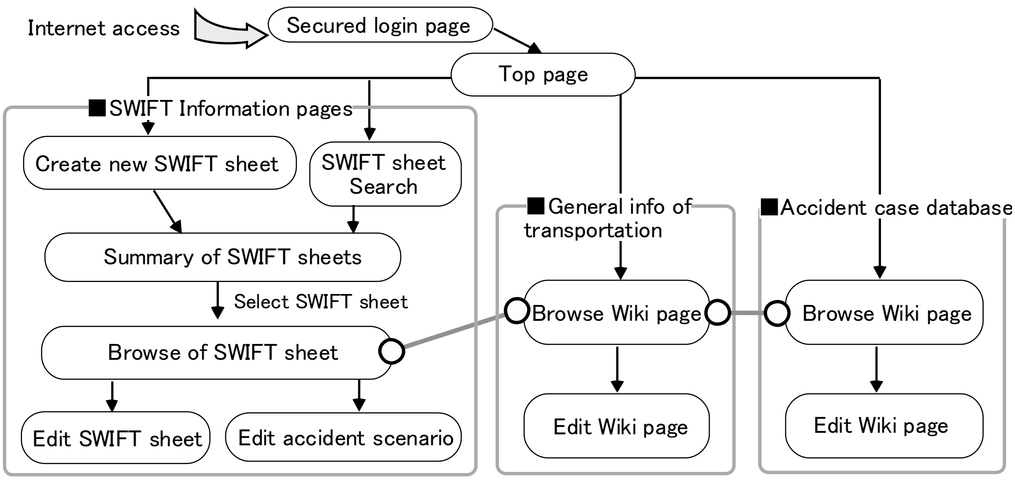


Figure 2. Page structure of the accident scenario management system

Table 1. Examples of identified accidents potentially significant for domestic transport

Transport mode	Initiating event	Significant result	Remarks
Coast shipping by vessel	Collision with other ship	Direct impact to package	With a large ship of more than 30,000GT
		Thermal load by fire	Pool fire with oil tanker in particular
		Foundering after collision	Hard-to-salvage situation (e.g., over 200m depth)
	Fire/explosion in self-ship	Foundering after fire	Engine fire at open sea
	Sudden change to severe weather	Foundering or capsizing by severe storm or waves	Not to be caused by collision or fire
Cargo work by crane	Wire break, hook break or crane collapsing	Direct impact by package drop	On the ship hold
			On the berth or truck

3.2 Occurrence frequency data preparation for accidents of vessel and crane

Accident statistics of general vessels varies widely with ship type, accident type and sea area. Also, in most cases, it is hard to obtain the vessel traffic data by area or route, which is used as a divisor for frequency calculation. That is why estimated results of frequency could often differ with sources even for the same area. Thus we have prepared whole-route average data by accident type and also area-dependent data for collision, as shown in Fig.3 and Table 2[4]. The area-dependent traffic can be obtained as accurate as possible using cargo movements between domestic ports, Lloyd's ship movements and Automatic Identification System (AIS) data. Conveniently, AIS data enables to directly estimate frequency of collision with vessels more than 500GT in a specific route/area[6].

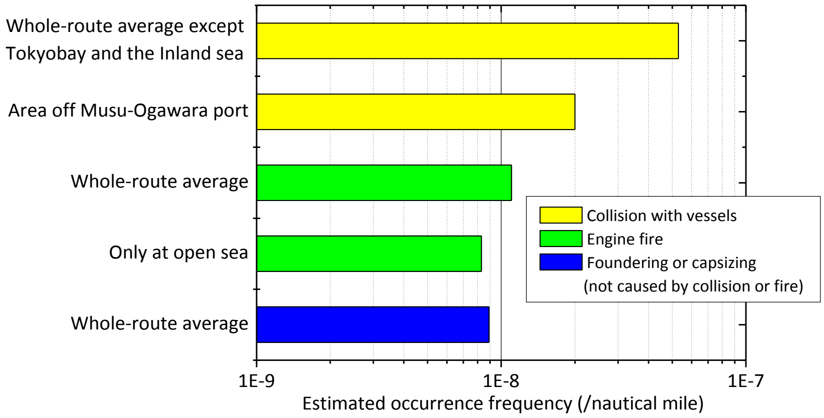


Figure 3. Estimated frequency of whole-route average and area-dependence by accident type

Table 2. Example of area-dependent traffic and collision frequency estimatior

Link No	Route segment	Distance (nm)	Traffic (vessels per day)		Collision Frequency (/nm)
			southbound (westbound)	northbound (eastbound)	
1	off Omaezaki-Tateyama	97	104.7	103.7	7.3E-08
2	off Tateyama-Choshi	86	50.5	46.2	3.5E-08
3	off Choshi-Kinkazan	158	33.8	30.2	2.2E-08
4	off Kinkazan-MutsuOgawara	173	30.7	26.7	2.0E-08

As accident statistics of crane can be rarely found, we have developed a method for estimating frequency of cargo drop using numbers of injuries and deaths caused by crane work. It also covers potential numbers of drops without any injuries. Figure 4 shows result of estimation with a foreign reference of OGP offshore records[7]. There is a good agreement between our lower limit and the OGP data for fixed crane. The use of lower limit is proper to our crane case due to carefulness of the work, so that we use a figure of 1E-4 (/operation) as frequency of the package drop.

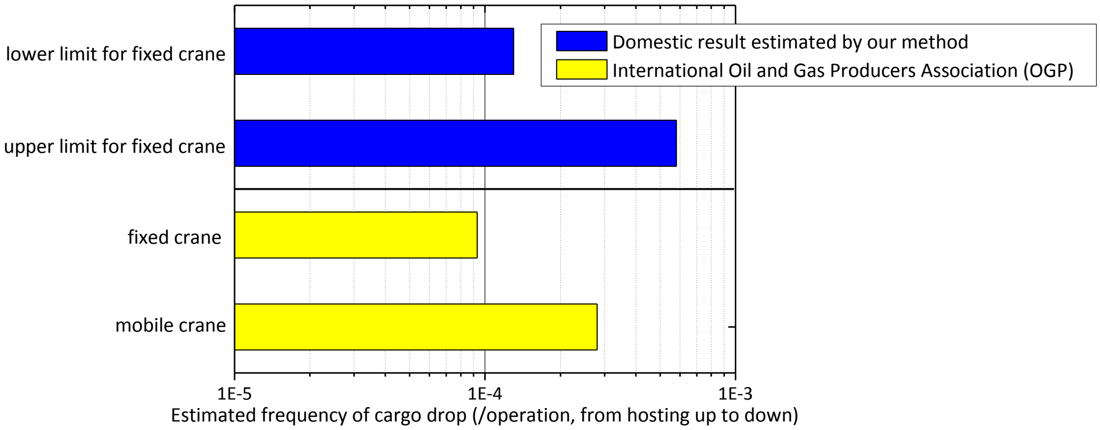


Figure 4. Estimated results of cargo drop from crane with a foreign reference

4 Case study of coast shipping SNF along the Pacific coast side of Japan

In this case study, a route example along the Pacific coast side is divided into four segments for comparison as shown in Table 2[3]. Figure 5 shows calculation results of health risk per operation. It is shown, unless salvage, that the foundering risk is dominant in any segment. It is assumed in this study that max capacity of 16 packages could be sunken at once and ingestion population of contaminated marine-products could be 2.7 million per day, which is conservatively estimated from whole fishery record of 5 prefectures on the Pacific side of Tohoku region. The figure of population is fairly doubtful so cauton must be taken for the absolute value of result. However the relative trend remains the same even if it is reduced to one-tenth. Another point of attention is a cause of foundering/capsizing. Through the event tree analysis, we have found that a collision with vessel of 2.2%, engine fire of 19% and others caused by wear of the ship, serious weather or wave. We should also mind other hazards than collision

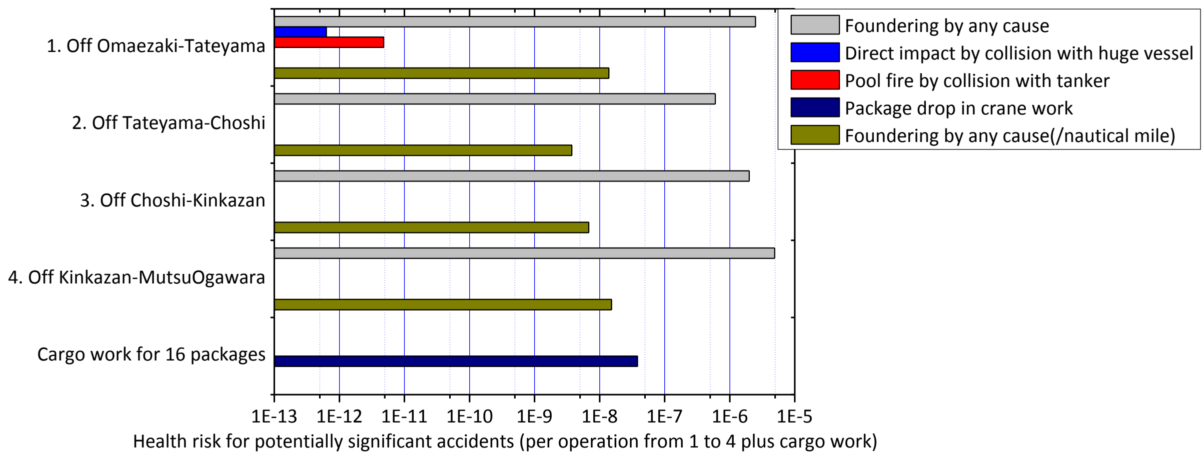


Figure 5. Estimated health risk for potential significant accidents (per operation)

and fire, e.g., sudden change of weather, although an exclusive ship has high stability.

The foundering risk depends on the water depth at the foundering location. Generally speaking, the deeper the water depth of sunken package is, the lesser the public exposure from ingestion is. It is because the habitat depth of the products we eat most is less than 100m. In other words, the deeper the sunken depth is, the lesser the quantity of radioactivity transferred from the seabed to the habitat by diffusion is. Figure 6 illustrates an example of dose evaluation for three sunken depths of 200m, 500m and 1,000m, simply taking diffusion for vertical direction into account. It is shown that, suppose the package cannot be salvaged, the exposure is dominated by the depth from 200m to 500m and that from the depth more than 1,000m will be negligible. The difference of the foundering risk (per nautical mile) between route segments shown in Figure 5 is made by the water-depth distribution along each segment. However it should be noted that diffusion in the true ocean is more complex and different by area and time.

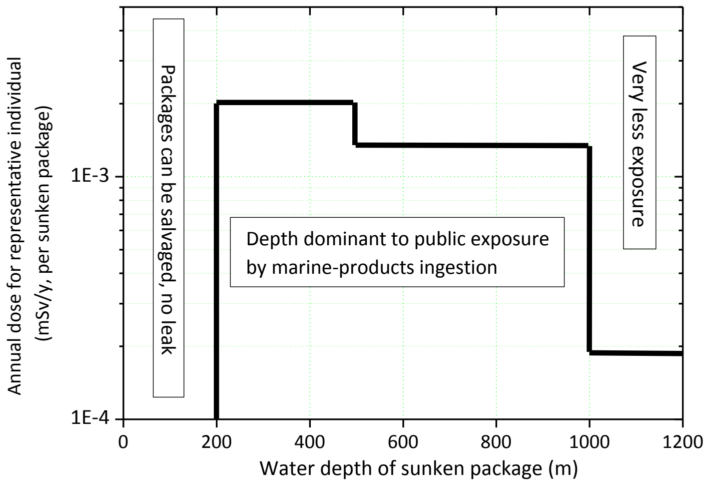


Figure 6. Example of relationship between public exposure by ingestion and the sunken depth

As the risk element other than foundering, small amount of contents release in the air could be conceivable for extreme conditions of direct impact and pool fire. However, the release point on the sea route is too far from the mainland so the public exposure is almost negligible. As an exceptional case as shown in the segment no.1 of Fig.5, the public risk could be posed to the people of the small island when the release occurs close to it, although it is quite less compared to the foundering risk. The other significant risk comes from potential release by the package drop at port cargo work. The amount of risk will be relatively large next to the foundering because max 16 packages is handled per vessel and so the frequency is getting higher.

Finally, current and future planned annual risks are roughly compared with that of land transport. Our cask geometry is similar to the train cask employed in US but the amount of stored SNF and inventory are rather different. It is shown from Fig.7 that the future-planned annual risk will approximately increase in proportion to the number of packages as compared with the current one and it still remains very low at a comparable level with the train accident risk of the YMEIS[8].

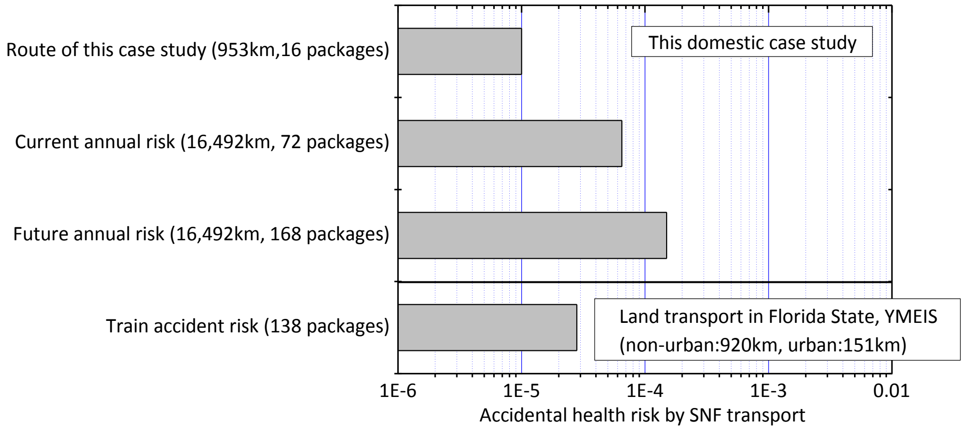


Figure 7. Current and future planned health risk by SNF transport with a reference of YMEIS

5 Conclusion

The risk evaluation process and method suitable for domestic SNF transport are described and our estimated data is used to perform a case study. The vessel foundering is found to be a dominant contributing factor to the accidental health risk. Further study is required to increase accuracy of parameter estimates such as the ingestion population.

References

[1] K.S. Neuhauser et al., RADTRAN5 Technical Manual, SAND2000-1256, 2000

[2] Y. Hirao, Evaluation of External Radiation Exposure of Workers Engaged in Loading of Radioactive Material Shipping Cask between Ship and Truck by Crane, Proc. 12th of International Conference of Radiation Shielding (ICRS12), 2013.

[3] Study on Risk Assessment Techniques for Radioactive Material Transport 2011, JNES report, Japan Nuclear Energy Safety Organization (JNES), 2012.

[4] Study on Risk Assessment Techniques for Radioactive Material Transport 2009, JNES, 2010.

[5] Study on Risk Assessment Techniques for Radioactive Material Transport 2010, JNES, 2011.

[6] Y. Hirao and F. Kaneko, Evaluation of Ship Movements and Collision Frequency via AIS in the Waters off Mutsu-Ogawara, Vol.125, The Journal of Japan Institute of Navigation, 2011.

[7] International Association of Oil & Gas Producers, OGP: Risk Assessment Data Directory, Mechanical lifting failures, Report No.434-8, March 2010

[8] US DoE, Draft EIS for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nevada, DOE/EIS-0250D, July 1999